

# **Hurricane Wave Topography and Directional Wave Spectra in Near Real-Time**

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## **LONG-TERM GOALS**

Develop a simple parameterization for the directional wave spectrum in the vicinity of a hurricane.

## **OBJECTIVES**

Develop and/or modify the real-time operating system and analysis techniques and programs of the NASA Scanning Radar Altimeter (SRA) to process the SRA wave topography data into directional wave spectra during hurricane flights. Upload the spectra and the topography onto a web site immediately post-flight to make them available to ONR investigators.

## **APPROACH**

The SRA has a long heritage in measuring the energetic portion of the sea surface directional wave spectrum (Walsh et al. 1985; 1989; 1996; Wright et al. 1999; 2001). There is an ambiguity of 180° in the direction of propagation of waves determined from topographic data. The FFT puts half the spectral energy in the real lobe and half in an artifact lobe that is perfectly symmetric with the real lobe. To obtain the directional wave spectrum, the energy of the FFT encounter spectrum must be doubled everywhere, the artifact lobes deleted, and the real lobes Doppler-corrected. Identifying the artifact lobes for deletion and partitioning the real spectral lobes into the various wave components has been a slow and labor-intensive process. Edward J. Walsh has overall responsibility for developing the techniques and corrections to enable this analysis to be performed during the aircraft flights. C. Wayne Wright will be responsible for the real-time operating system of the SRA and making whatever modifications may be required to enable near real-time processing of the data. He will also be responsible for developing and maintaining the web site for post-flight ONR access to the data.

## **WORK COMPLETED**

The SRA was installed on a NOAA WP-3D aircraft for the 2001 hurricane season and flights made into Hurricane Humberto on September 23 and 24, 2001. These directional wave spectra will expand our data base. There were significant time intervals when the SRA return signal was almost totally

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attenuated by rain at the 1.8 km altitude of the flights. The corresponding rain rates can be determined from the aircraft step-frequency microwave radiometer (SFMR). These data will be used for assessing rain effects on SRA data quality and making recommendations for the 2002 CBLAST experiment.

A comparison was made (Walsh et al. 2002) of the wave field components of Hurricane Bonnie on 24 and 26 August 1998 which suggests that a computer-aided screening process for deleting artifact lobes and partitioning the directional wave spectra is viable.

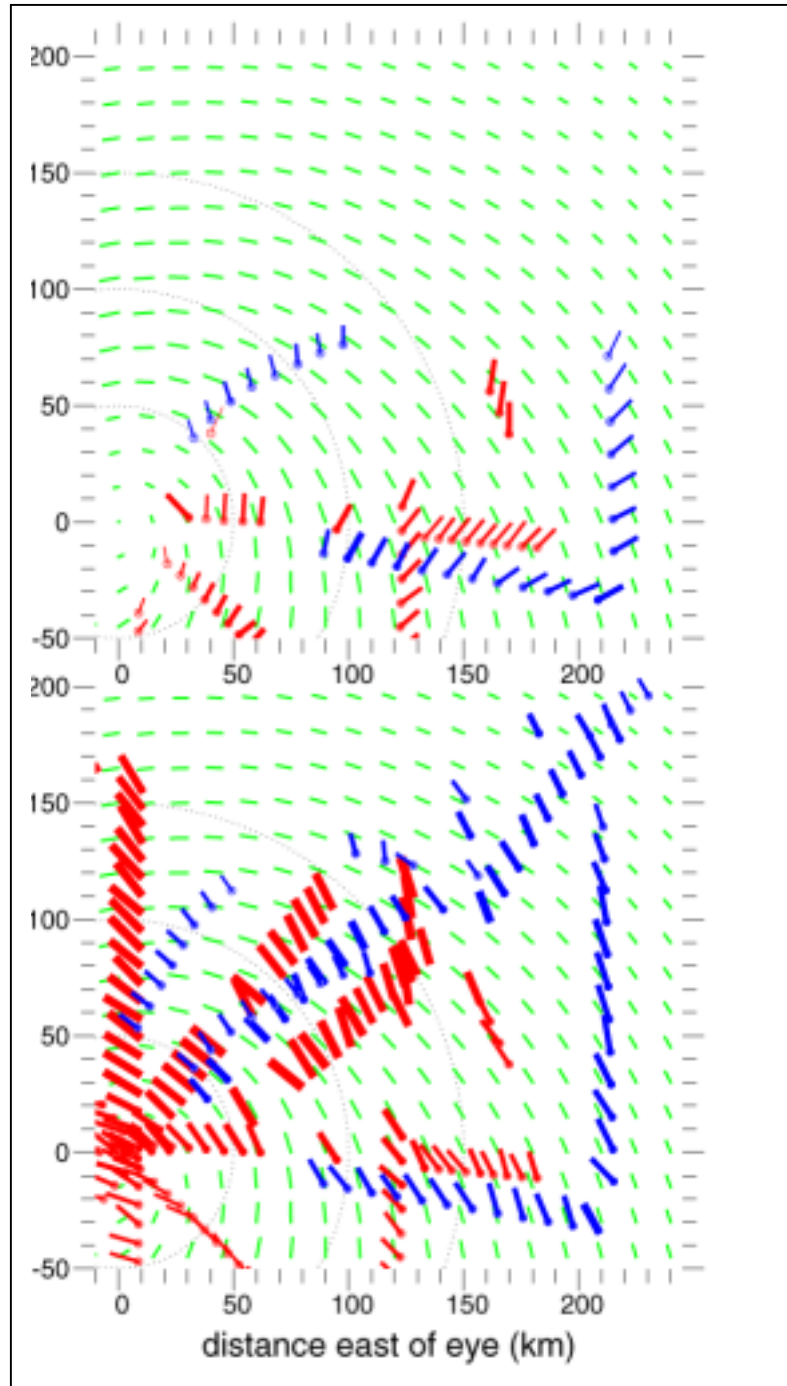
## RESULTS

NASA Scanning Radar Altimeter measurements made from a NOAA WP-3D hurricane research aircraft indicated a remarkable agreement in the propagation directions for the various wave components of Hurricane Bonnie on 24 August 1998 when it was in the open ocean and on 26 August when it was making landfall near Wilmington, NC. This was true despite differences in wave height and wavelength caused by shoaling and fetch-limiting at landfall. The maximum wind speed was lower at landfall (39 m/s) than when encountered in the open ocean (46 m/s) and the forward motion was faster (10 m/s versus 5 m/s in the open ocean), but the radius of maximum winds was about the same on the two days (80 km). This suggests that, in spite of its complexity, the directional wave field in the vicinity of a hurricane may be well behaved and lend itself to be modeled by a few parameters, such as the maximum wind speed, the radii of the maximum and gale force winds, and the recent movement of the storm.

Figure 1 shows, in a storm-relative reference frame, comparisons of the northeast- and northwest-propagating components on the two days in the right forward quadrant of Hurricane Bonnie. The blue radials represent wave components observed during the landfall flight of 26 August 1998 and the red radials represent the wave components observed during the open ocean flight on 24 August. The circles indicate the data locations and the radials extend in the wave propagation direction a length proportional to the wavelength. The width of the radials is proportional to the wave height so the aspect ratio is an indication of wave steepness. The green radials indicate the average of the wind speed vectors on the two days.

The directions of the red and blue radials show a remarkably similar spatial variation on the two days despite the shorter wavelength and lower wave heights caused by shoaling at landfall (blue) on August 26. There was also a remarkable similarity of wave component propagation directions in the left rear quadrant of Hurricane Bonnie on the two days (not shown), despite shorter wavelengths and lower wave heights for some components due to fetch-limiting at landfall.

The azimuthal orientations of the half-planes used to separate the real and artifact spectral lobes on the two days were determined by hand, totally independent of each other, as were additional radials used to partition the real portions of the directional wave spectra into the various wave components. The great similarity of the resulting components on the two days suggests that a common set of half-planes and radials could have been used. The gradual spatial variation of the directions of propagation suggests that a storm-centered model for the half-plane and partitioning radial orientations could be developed which could be used during the hurricane flights themselves. The approximate eye location



***Figure 1. Northeast- (top) and northwest-propagating (bottom) wave components in the northeast quadrant of Hurricane Bonnie on August 24 (red) and August 26 (blue), 1998.***

and expected movement are known at the start of each hurricane flight. This information could be used to determine the approximate storm-relative location for each encounter spectrum generated from the SRA topographic data. The spectral values could be represented in red on the artifact side and blue on the real side using a storm-centered model (to be developed) for their nominal orientations. Dashed radials could be shown on the real side for the nominal spectral partitions. This would allow the

operator to make immediate value judgments as to how well the nominal orientations fit the actual spectrum and quickly develop adjustments to the nominal values for the particular storm being flown.

## **IMPACT/APPLICATIONS**

The SRA is providing the first quantified measurements of the directional wave spectrum spatial variation in the vicinity of hurricanes. The data will impact all the assessments of air/sea interaction in the hurricane environment and serve as a basis for validating wave models under those extreme conditions. The ability to be able to examine the three dimensional structure of individual waves and wave groups will also be very important for assessing the viability of various marine structures.

## **TRANSITIONS**

The SRA directional wave spectra will be used by other investigators to provide a basis for the interpretation of the wave effects on the air/sea quantities of interest to ONR.

## **RELATED PROJECTS**

All hurricane components of ONR CBLAST.

## **SUMMARY**

The NASA Scanning Radar Altimeter produces a topographic map of the sea surface by scanning a narrow (1\_) beam across the aircraft ground track at 10 Hz and measuring the range to 64 points across a swath whose width is 0.8 of the aircraft height. This enables study of the characteristics of individual waves, groups of waves, and the directional wave spectrum. Since the wave field is the air/sea interface, knowledge of it is important in the study of processes at the air/sea interface.

Because it requires both time and distance for waves to grow, their properties tend to represent averages over the wind field temporal and spatial variations. The spatial variation of the direction of propagation of the various components of the complex directional wave spectrum of Hurricane Bonnie showed a remarkable similarity in open ocean and while making landfall. This suggests that the hurricane wave field may be a well-behaved function of a few simple parameters such as the maximum wind speed, the radii of maximum and gale-force winds, and the recent motion of the eye. This research is being pursued through the analysis of SRA data from other hurricanes.

The early analysis suggests that the hurricane wave field spatial variation is similar enough to automate a preliminary recommendation on which of the wave components are real and which are artifacts of the FFT used to generate the spectra. The operator could then apply corrections to the recommendation.

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## **PUBLICATIONS**

Walsh, E. J., C. W. Wright, D. Vandemark, W. B. Krabill, A. W. Garcia, S. H. Houston, S. T. Murillo, M. D. Powell, P. G. Black, F. D. Marks, 2002: Hurricane directional wave spectrum spatial variation at landfall, *J. Phys. Oceanogr.*, in press.

## **PATENTS**

None.